

Forage Genetics and Production

Polyphenol-Containing Forages: A Way to Improve the Profitability and Nitrogen-Use Efficiency of Dairy Farms?

J.H. Grabber, G.A. Broderick, R.D. Hatfield, J. M. Powell, M.P. Russelle and R.E. Muck.

Poor protein utilization is a problem on dairy farms

Forages like alfalfa are potentially a superb source of protein for livestock. The per acre protein yield of alfalfa is 50% greater than soybeans and its crude protein content should be high enough to meet the requirements of most dairy cattle. Unfortunately, most of the protein in alfalfa is degraded in the silo and rumen, impairing protein utilization by the cow. This leads to excessive nitrogen excretion in urine, increasing the amount of nitrogen that must be either recycled through crops or lost to the environment. Protein utilization by dairy cattle can be improved by several means, but each has shortcomings. Excessive protein breakdown in the rumen and nitrogen excretion by livestock is reduced if annual row crops like corn and soybeans are used to meet much of the nutritional requirements of lactating dairy cattle. Unfortunately, production of row crops in place of perennial forages dramatically increases the risk of soil erosion and nutrient loss from cropland to the environment. Alternatively, purchased protein supplements increase the cost of milk production and can lead to excess nitrogen and phosphorus accumulation in soils and greater loss of these nutrients from farmland. Post-harvest treatment of forage with formic acid or other additives can reduce protein degradation in ensiled forages and improve protein use by dairy cattle. However, concerns about cost, equipment corrosion, or safety currently preclude the widespread use of these treatments.

Polyphenols can improve protein utilization

Protein utilization on dairy farms is enhanced if forages containing polyphenols are grown and fed to cattle. Modest levels of polyphenols (perhaps 2-4% of dry matter) bind to proteins, reducing proteolysis during ensiling and rumen fermentation by up to 50%. These levels, however, will permit extensive protein digestion in the abomasum and subsequent uptake of amino acids by the small intestine without adversely affecting carbohydrate digestibility or reducing feed intake. Some forage and grain crops (e.g. red clover, some varieties of birdsfoot trefoil, and grain sorghum) contain adequate levels of polyphenols for enhancing protein utilization by cattle. However, most feeds used on U.S. dairy farms (e.g. alfalfa, corn silage, corn grain, grasses, and soybean) contain very low levels of polyphenols (< 0.2% of dry matter), insufficient for improving protein use.

Feeding trials at the Dairy Forage Center have demonstrated the value of polyphenols in red clover for reducing wasteful protein breakdown during ensiling and rumen digestion and for improving protein use-efficiency of dairy cattle. This research is described elsewhere in our 2000/2001 Research Summaries. These trials also revealed that fiber digestibility of red clover based rations is 22% greater than alfalfa based rations, reducing excretion of manure by 19%. Although these traits increase the value of red clover, further adoption of red clover in dairy feeding systems will be limited unless improved cropping systems for this forage are developed.

The benefits of condensed tannins (another group of polyphenols) for improving protein utilization and ruminant performance are well documented in New Zealand for sheep and cattle fed pasture or green-chopped forages. Feeding trials with sheep demonstrated that increasing tannin concentrations from trace amounts to 4% of dry matter increased the flow of feed protein into the small intestine by 30%. Absorption of essential amino acids by the small intestine was increased by up to 60% in sheep diets containing as little as 2% tannin on a dry matter basis. In a recent study, milk production of non-supplemented Holstein cows was increased by 2.7 kg per day by tannins in birdsfoot trefoil. The potential for tannins to improve protein utilization and milk production of dairy cattle have not, however, been evaluated in forage-concentrate rations typically fed on U.S. dairy farms.

Tannins (and probably polyphenols in red clover) also shift nitrogen excretion from urine to feces and from soluble to insoluble nitrogen forms in feces. Moreover, a greater proportion of fecal nitrogen is in undigested plant residues—a form which mineralizes more slowly than microbial and endogenous nitrogen. These shifts in nitrogen forms could reduce ammonia and nitrate losses from dairy cow facilities, manure storage tanks, and manure-amended fields.

Tannins may also effect the overall cycling of nitrogen and carbon in forage-based cropping systems for dairy farms. In one study, three-year stands of alfalfa and birdsfoot trefoil, managed as hay, supplied about the same amount of nitrogen to three succeeding years of corn. Compared to alfalfa, birdsfoot trefoil provided 20% less nitrogen in the first year (without a reduction in yield), and about 50% more nitrogen in the second and third year of corn production. The more uniform mineralization of nitrogen from birdsfoot trefoil residues might be due to tannins; studies with green manure crops and tree litter indicate that polyphenols like tannins slow the mineralization of nitrogen and carbon in soil. A more gradual mineralization of nitrogen from crop residues and manure could reduce nitrate losses from cropland, especially when forage legume fields are manured and plowed prior to the first year of corn production (a common, albeit not recommended practice on dairy farms). Although not documented, similar shifts in nutrient partitioning and cycling on U.S. dairy farms (which often have excess nitrogen) could reduce nitrogen losses from manure during excretion, storage, and field application. These shifts may also improve crop uptake of nitrogen and the sequestering of carbon in soils. Because perturbation of nutrient cycles can have surprising outcomes, it is imperative that we measure the actual impact of polyphenols on dairy-forage systems before pursuing adoption of a new practice or technology.

Polyphenol Research at the Dairy Forage Center

Efforts are underway to understand the biochemical mechanisms behind the more efficient utilization of protein in red clover. We will continue feeding trials with polyphenol containing crops (birdsfoot trefoil and red clover) to identify optimal polyphenol concentrations for improving protein utilization and milk production of dairy cattle. Other studies will evaluate how polyphenols influence nitrogen loss from manure during excretion, storage, and land application and the cycling of nitrogen in crop rotations. We are also examining the role of forage polyphenols for improving the sequestration of carbon in soil. Short rotations of red clover with cereal crops are being designed and tested to take greater advantage of the aggressive establishment, slower maturation, and high initial productivity of this polyphenol-containing forage species. Integrated nutrient cycling, crop, and dairy nutrition models (e.g. DAFOSYM) are being used to plan studies and to assess the farm-scale and national impact of incorporating polyphenol-containing crops on to dairy farms. A preliminary DAFOSYM study evaluating polyphenol impacts on dairy farms is included in the current Research Summaries.

These efforts will identify optimal polyphenol concentrations and management practices for improving protein and nitrogen use on dairy farms. Our efforts will also stimulate and support work in the public and private sectors to develop forages with optimal polyphenol levels for enhancing protein and nitrogen utilization by dairy farms.

Potential Impact of Tannin-Containing Alfalfa on the Profitability and Nitrogen-Use Efficiency of a Wisconsin Dairy Farm

J. H. Grabber, C.A. Rotz, D.R. Mertens, and R.E. Muck

Introduction

Tannins bind to forage proteins, potentially altering protein and N availability during ensiling, ruminal digestion, and decay of residues in soil. Most feeds used on U.S. dairy farms (e.g. alfalfa, corn silage, corn grain, grasses, and soybeans) contain inadequate levels of tannins (< 0.2% of dry matter) for affecting N cycling. Plant breeding and biotechnology efforts are underway in the U.S. and abroad to develop alfalfa and other forages with modest amounts of condensed tannins. We used a dairy-farm simulation model (DAFOSYM) to predict the impact of growing and feeding an alfalfa with 2% tannin on a dairy farm in southern Wisconsin.

Methods

Based on limited published data, we assumed that tannin would reduce rumen-degradable protein of alfalfa by 20%, increase acid-detergent insoluble N of alfalfa by 30%, and reduce the N mineralization rate of alfalfa residues in soil by 30%. The simulated farm had 100 cows, 85 heifers, and 250 acres of medium silt-loam soil. In rotation with corn grown for silage and grain. Alfalfa for hay or silage was cut with a conventional mower-conditioner and grown. Alfalfa for hay was also cut with an improved mower-macerator developed by the Dairy Forage Center. High-forage rations were fed using homegrown feeds and purchased corn grain, roasted soybeans, soybean meal, fat, and minerals. Cows were injected with BST and milked twice daily. Manure and bedding were stored in a lagoon and shallow-injected into corn ground in the spring and autumn to minimize ammonia losses. Simulations were run using 25 years of weather data from Madison, Wisconsin.

Results and Discussion

In general, use of normal or tannin-containing alfalfa did not affect yields of forage or grain (Table 1). Due to lower manure N excretion by cattle and lower residue N availability with tannin-containing alfalfa, corn-based system (6) required small amounts of additional N fertilizer. Milk yields were greatest with rations based on tannin-containing alfalfa or corn silage. Use of tannin-containing alfalfa in place of normal alfalfa reduced protein purchases by 27 to 57 tons, reduced nitrogen losses by 6 to 30 lb per acre, and increased net return per cow by \$62 to \$118 per year. Tannins increased the value of alfalfa silage by \$24 to \$32 and alfalfa hay by \$12 per ton of dry matter. Feeding tannin-containing alfalfa shifted grain purchases from lower yielding soybeans to higher yielding corn, reducing the need for off-farm production of potentially erosive and nitrate leaky row crops by 8 to 23 acres. Benefits of tannin were greatest for alfalfa silage based systems. Conventional hay systems were not competitive (data not shown), yielding annual net returns of

about \$50 less per cow than alfalfa silage systems and \$110 less per cow less than the macerator-hay system. We are conducting cropping and feeding studies with birdsfoot trefoil (containing 1 to 4% tannin) and alfalfa to identify optimal forage tannin concentrations and management practices for improving protein and N use on dairy farms.

Table 1. Feed production, feed use, profitability, and environmental impact of a 100-cow dairy farm growing and feeding normal verses tannin-containing alfalfa silage or hay. Alfalfa for hay was mown with a macerator to speed drying rate and to improve forage quality. Alfalfa and corn silage were produced and fed in ratios of 3:2 (systems 1–4) or 3:7 (systems 5 and 6).

	System					
	1	2	3	4	5	6
Alfalfa conservation	Silage	Silage	Hay	Hay	Silage	Silage
Crops (ha)						
Alfalfa (A)	150	150	150	150	75	75
Corn (C)	100	100	100	100	175	175
Rotation (crop-years)						
	A-3	A-3	A-3	A-3	A-3	A-3
	C-2	C-2	C-2	C-2	C-7	C-7
Tannins in alfalfa	No	Yes	No	Yes	No	Yes
Crop yields (t/a)						
Alfalfa silage	4.3	4.3	4.2	4.1	4.3	4.3
Corn silage	6.3	6.3	6.4	6.4	6.1	6.1
Corn grain	2.9	2.9	2.9	2.9	2.8	2.8
Feed (t DM)						
Alfalfa fed	502	502	517	515	236	237
Corn silage fed	329	329	351	351	565	565
Homegrown dry grain fed	116	116	108	108	124	124
Forage sold	14	9	15	12	16	11
Corn grain purchased	158	219	141	175	121	160
Soy meal 48% purchased	47	36	36	50	69	65
Roasted Soy purchased	64	18	55	14	71	36
Animal/vegetable oil	6	6	6	7	6	6
Milk production (lbs/cow)	27,370	27,770	27,090	27,430	27,900	28,100
Net return (\$/cow/year)	1,975	2,093	2,033	2,095	1,976	2,052
SD of net return (\$/year)	78	89	89	103	86	98
Manure on corn land (%)	100	100	100	100	100	100
Fertilizer N (lb/a)	0	0	0	0	50	75
Nitrogen losses (lb/a)						
N volatilized	82	66	65	59	68	64
N leaching	17	11	13	10	12	11
Denitrification	22	14	16	11	15	14
N in leachate (ppm)	11.8	8.0	9.1	6.9	8.4	7.9

Phytofiltration to Remediate High-Nitrate Ground Water: Initial Tests of the Concept.

M.P. Russelle, D.W. Kelley, M.D. Trojan, E.P. Eid, J.F.S. Lamb, and J.A. Wright.

Introduction

Nitrate moves readily through soil with percolating water, and is a common problem in shallow aquifers of the USA. Compliance with the public drinking water standard of 10 mg NO₃⁻-N/L often involves construction and maintenance of a water treatment facility. In the case of one public rural water supplier, Lincoln-Pipestone Rural Water in southwestern Minnesota, it involved building a \$2 million facility that requires several hundred thousand dollars in operating expenses annually. An alternative approach to remediate water from shallow aquifers in humid and subhumid areas may be phytofiltration. The concept is that NO₃⁻-laden water from the aquifer is irrigated onto a growing crop, using water rates that promote leaching of water back into the aquifer. In theory, the actively growing crop absorbs the NO₃⁻ to produce plant proteins, while a portion of the irrigation water returns as clean water to the aquifer. Perennial, cool-season forages offer several important advantages over annual crops in phytofiltration, including their long growing period, high yield, high nutrient need, high quality (and value), reduced runoff and soil erosion, improved soil quality, and deep root system.

Methods

We conducted this research at two sites in Minnesota, Pipestone in the southwest and Becker in central Minnesota. Alfalfa (*Medicago sativa* L.), orchardgrass (*Dactylis glomerata* L.), and brome grass (*Bromus inermis* L.) were seeded in duplicated plots (23 X 23 m) on a silty clay loam soil at Pipestone in spring 2000, and these forages plus soybean [*Glycine max* (L.) Merr.] were seeded in replicated plots (2 X 6 m) on a sandy loam soil at Becker in spring 1999. About 2.5 cm of water was applied twice weekly during the growing season with a solid set sprinkler system at Pipestone and a surface drip system at Becker. Irrigation water concentrations ranged from approx. 15 to 50 mg N/L. At Becker, we added either ¹⁵N or Br as a tracer for NO₃⁻ uptake by the crops. Forage harvests followed typical practices in the area, with three or four cuttings annually in established stands. Soybean was harvested at physiological maturity. Plant samples were analyzed for total N and for the tracers, where applicable. Ground water samples were obtained in spring 2000 at Pipestone to evaluate NO₃⁻ concentration at upgradient and downgradient locations under these large plots.

Results and Discussion

Estimated recovery of NO₃⁻ in irrigation water in 2000 at Becker was 55% in orchardgrass and alfalfa, but only 25% in soybean and brome grass (Fig. 1). Highest yield and N harvest were obtained with alfalfa, lowest with smooth brome grass. Soil solution nitrate concentrations were generally very low under the perennial forages and considerably higher under soybean (Fig. 2). The disparity between moderate removal of N (as measured in shoots) and the low soil solution concentrations indicates that denitrification likely was occurring.

No differences were observed in NO₃⁻ concentration in ground water at Pipestone. This may indicate that the method is not effective, or may have been due to insufficient water recharge (irrigation began only in mid-summer 2000), to rapid movement of the groundwater (causing us to miss the low-NO₃⁻ plume), or to N loss by denitrification.

Theoretically, we should be able to improve water quality, if only dilution, using this approach. For example, using a drinking water supply requirement of 3 ML/d, which is the need at the Pipestone location, 20 mg NO_3^- -N/L in the aquifer, and leached N of 5 mg NO_3^- -N/L, a total of 15.4 ML/week of clean water needs to be returned to the aquifer to reach a target NO_3^- concentration of 9 mg NO_3^- -N/L. A standard quarter-section irrigation pivot applies 13.0 ML in a 5.0-cm depth, which implies that two such sections in the neighborhood of the drinking water supply wells should be sufficient during the cropping system.

Conclusion

Removal of nitrate appears to involve both N uptake and denitrification. This remediation approach has potential in areas where ground water can be readily influenced by leaching. More generally, it appears that perennial forages could be used to remove nitrate from sources such as wastewater or aerobic lagoon water applied through irrigation systems to prevent ground water contamination. Phytoremediation will be much less effective during periods when crop growth slows (immediately after harvest, in late autumn as plants enter dormancy, or when temperatures are too cold or hot for rapid growth). Even if water treatment can be avoided for 5 or 6 months of the year, the operating costs for the drinking water facility will decline.

Partial funding was provided by the Legislative Commission on Minnesota Resources through the Minnesota Future Resources Fund.

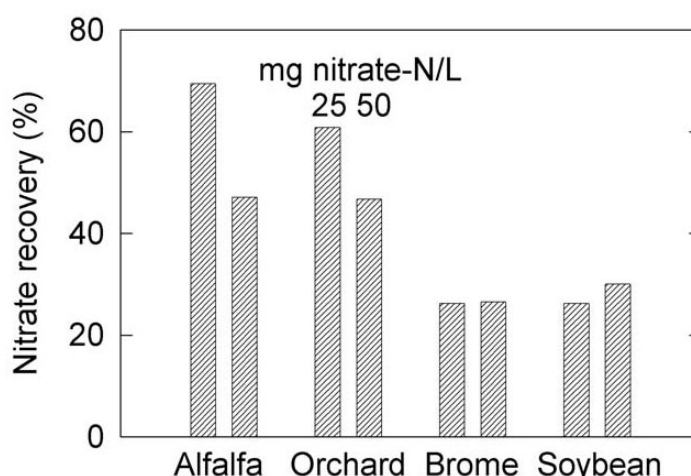


Fig. 1. Apparent NO_3^- -N recovery by soybean and three perennial forage crops grown at Becker, MN, 2000, from irrigation water containing either 25 or 50 mg NO_3^- -N/L.

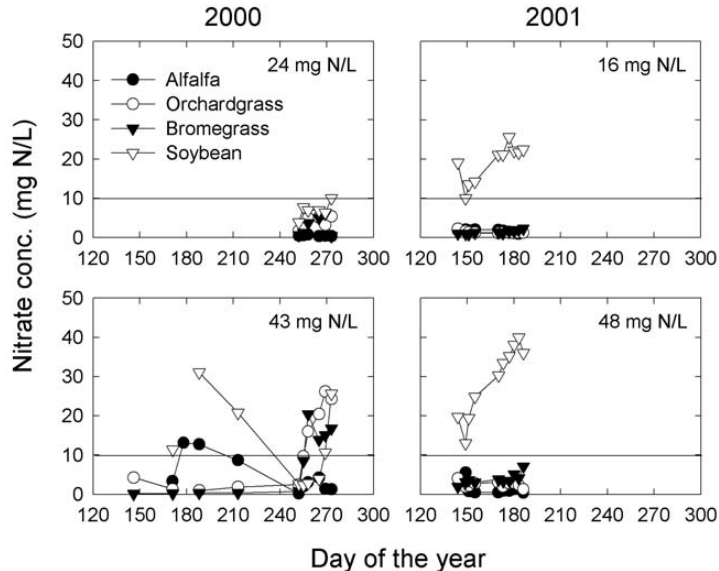


Fig. 2. Soil solution $\text{NO}_3\text{-N}$ concentration at the bottom of the root zone of four species during two growing seasons at Becker, MN.

Predicting Impacts of Crop Management on Nitrate Leaching in a Wellhead Management Area.

M.P. Russelle and D.W. Kelley

Introduction

Rural water supply quality is frequently compromised by high nitrate concentration. Although there are many sources of ground water nitrate, nonpoint sources such as fertilizer and manure N can be quite important in agricultural areas. We are working with the Lincoln-Pipestone Rural Water Supply District (LPRWSD) in southwestern Minnesota to devise ways to limit nitrate contamination of their aquifers. These shallow aquifers are easily affected by nitrate that leaches below the root zone, but leaching is highly dependent on the soil texture and depth in a field, what crop is grown, how much N is applied, whether supplemental irrigation is provided, and, of course, weather. Perennial crops can help reduce nitrate leaching by reducing both soil nitrate levels and water flow in spring, when leaching losses are usually highest in the North Central Region. Spring growth of alfalfa and other cool season perennial forages results in higher water use through evapotranspiration than with corn (evaporation only at this time), and reduces the amount of water loss by gravity through the soil. Nitrate leaching on fine-textured soils is uncommon during late summer, when crop water use is high, so neither corn nor alfalfa are likely to lose nitrate via leaching during this time. The majority of land in the LPRWSD wellhead management areas (WMA) is cropped to corn soybean. Our purpose in this research was to evaluate the likely impact of crop management on nitrate leaching in one of their WMAs.

Methods

We used a computer simulation model called GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) with soils information from the Holland wellfield area (near Pipestone, MN) and ten years (1989-1998) of local historical weather data. We first calibrated and validated GLEAMS using detailed data from experiments conducted by others in the region. We simulated the effects of growing alfalfa, continuous corn at three N rates (115, 145, and 180 kg N/ha), and corn-soybean rotations at one N rate (100 kg N/ha on corn) on all major soils in the WMA (9000 ha). For the corn-soybean rotation, we ran the simulation with corn in even-numbered years, repeated the simulation with corn in odd-numbered years, and then averaged the results by year over the two crops. We assumed maximum yields were 8800 kg/ha (140 bu/acre) for corn, 4400 kg/ha (65 bu/acre) for soybean, and 10,000 kg dry matter/ha (4 tons/acre) for alfalfa, based on typical 'good' yields in the area.

In the model, fertilizer N was applied as urea and immediately incorporated in late April, one week before planting corn. Simulations were conducted twice, once using precipitation only and once with supplemental irrigation. The modeled irrigation regime was conservative; water was not applied until the soil dried to 25% of the available soil water holding capacity, and water was added only to 90% of the water holding capacity, so irrigation *per se* did not exacerbate leaching. Applied water was assumed to contain 5 ppm nitrate-N. No attempt was made to delay irrigation if precipitation would occur within a day or two, and thus, the model reflected the reality farmers face in needing to irrigate when precipitation is not a certainty.

Results

GLEAMS predictions supported our hypothesis that nitrate leaching under alfalfa is lower than under annual crops, like corn and soybean. The model predicted only rare leaching events under alfalfa, but it predicted high nitrate concentrations in the soil solution. This latter result does not agree with data in many experiments, which show that soil solution nitrate-N concentrations under alfalfa are typically much lower than 10 ppm. If water escapes the root zone of perennial forages during spring, it may help improve ground water quality as long as the nitrate concentration of this percolating water is low.

Average predicted corn grain yield increased on some soils with 130 compared to 100 lb N/acre, but little further gain was achieved with 160 lb N/acre. This result also occurred in simulations using a higher yield potential, lending credence to University of Minnesota fertilizer recommendations. The amount of water percolating below the corn root zone did not change with fertilizer N rate, but nitrate concentrations in that water increased rapidly when excessive fertilizer N was applied, leading to very high N losses on some soils.

Irrigation increased leaching losses, mainly due to increased water percolation during May through August, because of decreased soil water storage capacity when heavy rainfall occurred. In addition, late season irrigation reduces the capacity of soil to store snowmelt and rainfall in spring. Even with the conservative irrigation regime in this simulation, the amount of water percolating below the root zone increased by an average of 30 to 35% on most soils, and nitrate concentration increased to a variable degree.

We estimated the total average annual N loss via leaching by combining the per-acre loss and the area of each modeled soil in the Holland WMA. Even when per-acre leaching losses were small, total losses were predicted to be over 13,000 kg N if the entire WMA were growing continuous corn under nonirrigated conditions with 112 kg N/ha spring fertilizer applications. Under nonirrigated conditions, total nitrate-N losses under continuous corn tripled as fertilizer N rate increased from 112 to 145 kg N/ha, and doubled again when rate increased to 179 kg N/ha. Nitrate losses were similar for a corn/soybean rotation and for continuous corn with modest N rates under dryland conditions, but 40% more nitrate was lost under the corn/soybean rotation than under continuous corn under irrigation. We think this is due to lower water use and lower nitrate uptake by the soybean than by corn, even though more than twice as much fertilizer N is applied in the continuous corn system. We produced maps of predicted nitrate losses under different cropping scenarios. These color maps cannot be reproduced here, but provide an excellent means for the LPRWSD managers to visualize which fields may be contributing to ground water nitrate.

It is clear that nonpoint nitrate losses below the root zone of annual crops in the WMA may be contributing to the increasing nitrate concentrations measured in the water table. It is possible that less diffuse sources (e.g., barnyards with excessive manure deposition, leaky septic systems, surface water affected by tile drainage, etc.) are sources of nitrate, as well. This analysis does not include all possible management scenarios, and although results cannot be considered exact, they should be useful for designing cropping systems to improve and protect future ground water quality in the Holland WMA. Furthermore, this approach should be quite effective for water managers in other WMAs overlying shallow aquifers. Diversifying corn-soybean rotations with perennial forages, like alfalfa, can help protect water quality, particularly if 'leaky' soils are identified and targeted for perennial plantings.

Alfalfa Root System Architecture and Phosphorus Uptake

M.P. Russelle and J.F.S. Lamb

Introduction

Plant root systems have a genetically determined architecture that is typical of a species, but that architecture is also influenced by growing conditions. Plant root system architecture can have a large influence on the ability of a plant to obtain nutrients and water from the soil and to penetrate dense soils, and also affects the use of photosynthate, the food produced by the plant in sunshine.

Alfalfa is known as a deeply rooted perennial forage that can remove nitrate-nitrogen and other nutrients and water from deep in the soil. Plant breeding techniques have been used to develop alfalfas with different root system architectures – one being strongly tap-rooted with few fine lateral roots, the other being strongly branch-rooted with many fine lateral roots. The questions we asked with the research were: 1) Does alfalfa root architecture affect phosphorus uptake? 2) Does P availability in the soil affect the expression of root system architecture?

Methods

Two experiments, representing 5 site-year combinations, were conducted in Minnesota on either a loam or sandy loam soil. We grew a parent population (UMN2987, a composite of the best modern

varieties available in 1992) and selections for tap rootedness or branch rootedness (either first and second or only second cycles of selection). Plants were seeded in spring 1997, spaced 7.5 cm apart in a grid within each plot to allow individual plant sampling and equal rooting volume for each plant. Fertilizer P was injected after the first harvest in the 0 to 40-cm depth on a 3.8-cm grid spacing.

Forage was harvested twice in the year of establishment and 4 or 5 times annually thereafter. Roots were sampled by undercutting the plots (experiment 1) or taking 7.5-cm diam. cores directly over the plants (experiment 2) after one, two, or three cropping seasons. Forage yields, root system architecture (root mass, root length, fine vs. thick roots), and forage P uptake were measured.

Results

Bray-1 extractable soil test P levels ranged from 7.1 to 16.5 mg P/kg soil in unamended plots and were higher (16.3 to 25.8 mg P/kg) in P-amended plots, but P fertilization did not affect any measured plant parameter, except herbage P concentration and P uptake, in either experiment. There were no interactions of P rate and alfalfa entry.

Selections for root system architecture also involved plant size, as only the largest plants were kept in the selected populations. As a result, forage yields increased in both tap- and branch-rooted selections (mean 13,400 kg dry matter/ha in experiment 1, for example), compared to the parent population (mean 11,100 kg/ha in experiment 1). Fewer lateral roots generally were present in the tap-rooted selection and more generally were present in the branch-rooted selection, as compared to the parent population.

A greater proportion of the root system was present as secondarily thickened roots in the tap-rooted selection below 40 cm, but the tap-rooted selection also produced more fine-diameter roots than the branch-rooted selection. Fine root length densities ranged from about 10 cm/cm³ in the upper 15 cm of soil to about 1 cm/cm³ below 30 cm in 1997 in experiment 2 and from nearly 5 cm/cm³ in the top 15 cm to 1.5 cm/cm³ in the 45 to 60-cm depth in 1998.

Conclusions

It is revealing that simple selection for plants with large biomass within a composite of modern commercial cultivars increased herbage yield by 21%. This required selection for root and crown mass, rather than simply herbage mass, as is done in most commercial plant breeding programs, but it suggests that such a selection procedure may have substantial benefits to farmers.

Selection of alfalfa for these root system architecture characteristics was successful and was maintained in different environments. However, the two different root system architectures did not affect P uptake by the plant. In hindsight, this result is not unexpected, given the observation that most of the difference in root system architecture occurred below the 40-cm depth, and the treatments had been applied in the upper 40 cm.

Further research should be conducted on the effect of these two root system architectures on nutrient and water extraction below 40 cm. In addition, it is important to evaluate the effect of root system architecture on other poorly mobile nutrients, such as K, which can be absorbed in luxury quantities by alfalfa and other forages, to the detriment of dry cows that consume this feed.